Carbon Footprint of Place-Based Economic Policies

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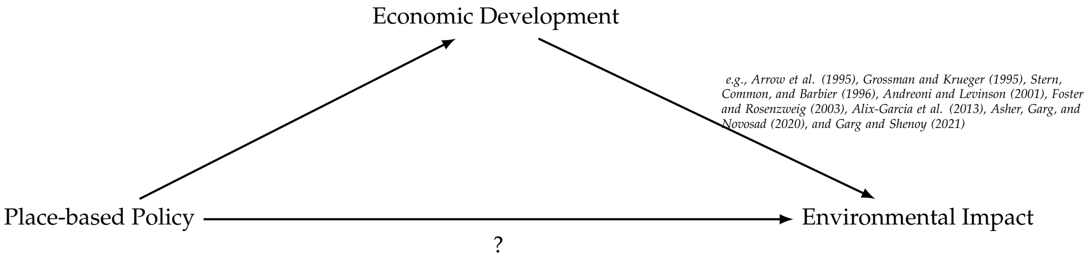
November, 2024 @ Stockholm School of Economics

Motivation

Research Question:

Can economic policies (e.g., place-based policies) produce environmental effects?



This Paper

- Examine the environmental consequences of Special Economic Zones (SEZs), a nationwide place-based policy designed to foster *economic development* in **India**
- Using large-scale firm-level data, we document the unintended and significant impact of SEZs on carbon emission
- Heterogeneous impacts across regions, firm types, and industries
- Establish a conceptual model to comprehend the findings

This Paper

- Complements the extensive literature on place-based policies
  e.g., Kline and Moretti (2014), Busso, Gregory, and Kline (2013), Ehrlich and Seidel (2018), Wang (2013), Lu, Sun, and Wu (2023), Neumark and Kolko (2010), Gobillon, Magnac, and Selod (2012), Neumark and Simpson (2015), and Rothenberg, Wang, and Chari (2024)

  Two related papers on India SEZs: *Görg and Mulyukova (2024) and Gallé et al. (2024)*

This Paper

- Emerging studies on the environmental impacts of place-based policies: mainly focusing on China, e.g., *Yu and Zhang (2022), Wang et al. (2023), Song et al. (2023), and Wen, Liu, and Huang (2023)*, and only one for India: *Garg and Shenoy (2021)*
  - India has also emerged as one of the top three carbon emitters globally, alongside China and the United States
- Contributes to the broader research on carbon abatement policies and sustainable development
  e.g., *Gillingham and Stock (2018), Colmer et al. (2024), Dechezleprêtre, Nachtigall, and Venmans (2023), and Gugler, Haxhimusa, and Liebensteiner (2021)*

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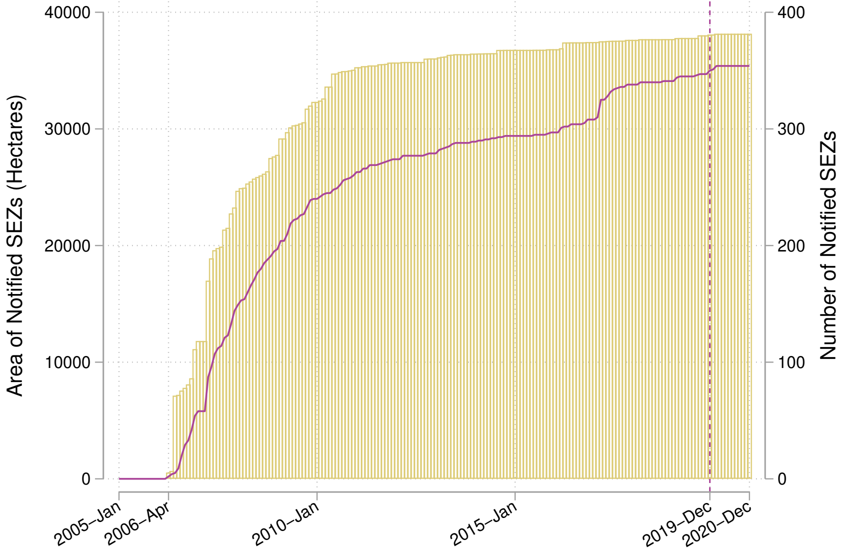
Background: India SEZs



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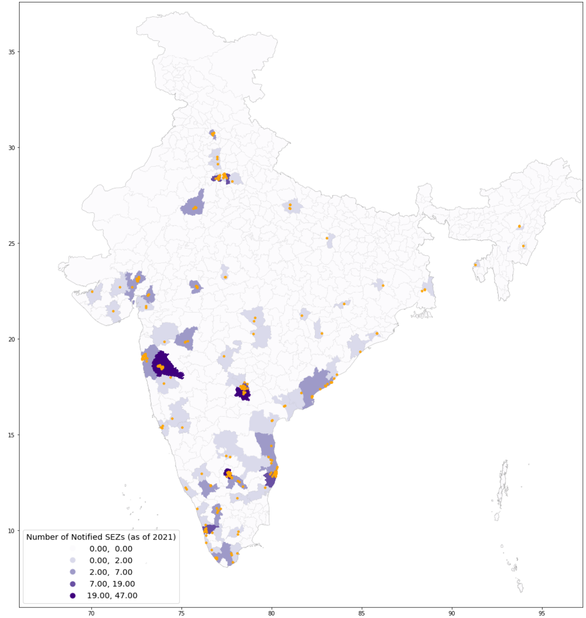
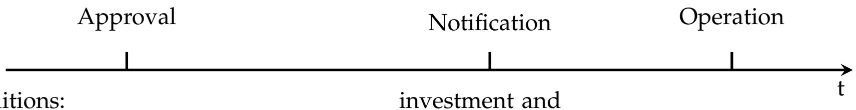


Background: India SEZs

- Administrative benefits: "single-window clearance"
- Fiscal benefits:
  - 100% income tax exemption on export income for the first five years of operation, reduced to a 50% exemption for the following five years
  - tax benefit of 50% on reinvested profits for a consecutive period of five years
  - exempted from sales and service taxes and, until 2012, from the Minimum Alternate Tax (MAT) which is a minimum tax rate of 18.5% on profits
  - duty-free import/domestic procurement of goods and services

Background: India SEZs



Conditions:

- the state government's endorsement of the project
- the developer's proof of land ownership
- the state government's provision of tax exemptions, assurance of adequate infrastructure, and clearance from state regulatory bodies

investment and construction initiated

Preview: Findings

1. Significantly lower carbon emission ($\sim 30\%$) for SEZ firms
2. Event study: no significant pre-trend + the SEZ-induced decline in carbon emission only becomes evident three years after SEZ notification
3. The effects are more pronounced among firms of *larger size*, in *non-manufacturing* sectors, and in regions with *growing renewable energy capacity*
4. SEZ firms:
   $\uparrow$ emissions and the share from renewable energy sources
   $\downarrow$ emissions from conventional energy sources

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Outline

- Introduction
- Data and Empirical Strategy
- Results
- Conceptual Model
- Discussion

Data

- Firm Data: Prowess 2000-2018
  - Firm Attributes: Age, Size, Type, Industry, Address, etc
  - Energy Consumption: Type, Quantity → Carbon Emission
    - Carbon Emission Factors
- SEZ Notification
  - Date, Address
  - Area

Empirical Strategy

A Spatial RD-DiD-Matching Framework:

- Spatial RD: Compare firms inside and outside SEZs. Confine the analysis to a 10 km $\times$ 10 km buffer around each SEZ.
- Matching: Construct treatment-control pairs by matching based on firm attributes: firm size, type, age, etc

▸ Summary Statistics-1 ▸ Summary Statistics-2

- DiD: Compare within treatment-control pairs before and after the SEZ notification

Empirical Strategy

Yellow squares represent the treatment zones, which are the same size as reported in the SEZ notification. Grey areas denote the "leave-out" zones, equivalent to a 2 km × 2 km square. The analysis sample is restricted to firms within a 10 km × 10 km grid, indicated by the purple box.

Empirical Strategy

$$Y_{it} = \beta After_{it} \times SEZ_{it} + \gamma_{ij} + \sigma_t + \delta_s + \kappa_d + \psi_k + \tau_{st} + \phi_{dt} + \varepsilon_{it} \quad (1)$$

- i, t, s, and d denote firm, year, state, and district
- Y_{it}: the annual carbon emission for firm i in year t
- $After_{it} \times SEZ_{it}$: $= 1$ if firm i in an SEZ after the notification year of the SEZ
- FEs: treatment-control pair (γ_{ij}), year (σ_t), state (δ_s), district (κ_d), and industry (ψ_k, classified by 8-digit CMIE industry codes), state-by-year (τ_{st}), and district-by-year (ϕ_{dt})

Empirical Strategy

$$Y_{it} = \alpha_k \sum_{k=6}^{2} Before_{i,t-k} \times SEZ_{it} + \delta_g \sum_{g=0}^{10} After_{i,t+g} \times SEZ_{it} \qquad (2)$$
$$+ \gamma_{ij} + \sigma_t + \delta_s + \kappa_d + \psi_k + \tau_{st} + \phi_{dt} + \varepsilon_{it}$$

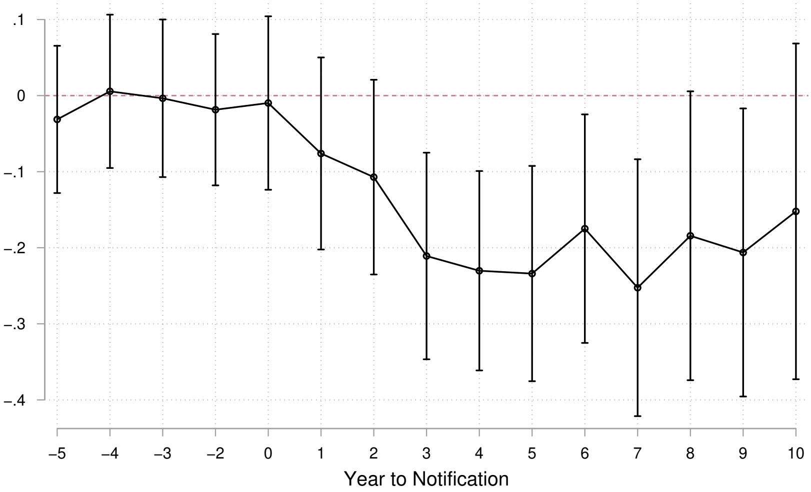
- $\text{Before}_{i,t-k}$ and $\text{After}_{i,t+g}$: time dummies indicating k years before the SEZ notification and g years after the notification

Main Results

	(1)	(2)	(3)	(4)
	Log(Carbon Emissions)			
β	-0.2032***	-0.2758***	-0.2902***	-0.2901***
	(0.0542)	(0.0579)	(0.0580)	(0.0628)
N	28290	28290	28290	28290
R^2	0.65	0.66	0.66	0.66
State-Year FE		✓	✓	
District FE			✓	
District-Year FE				✓

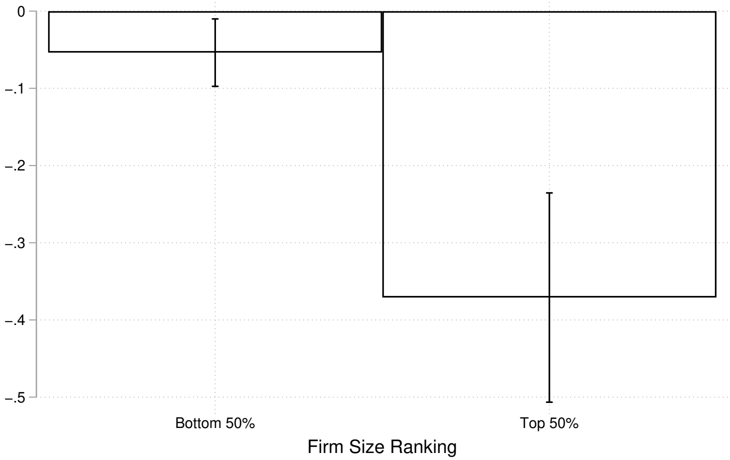
Notes: * p<0.10 ** p<0.05 *** p<0.01. Robust standard errors in the parentheses.

Main Results



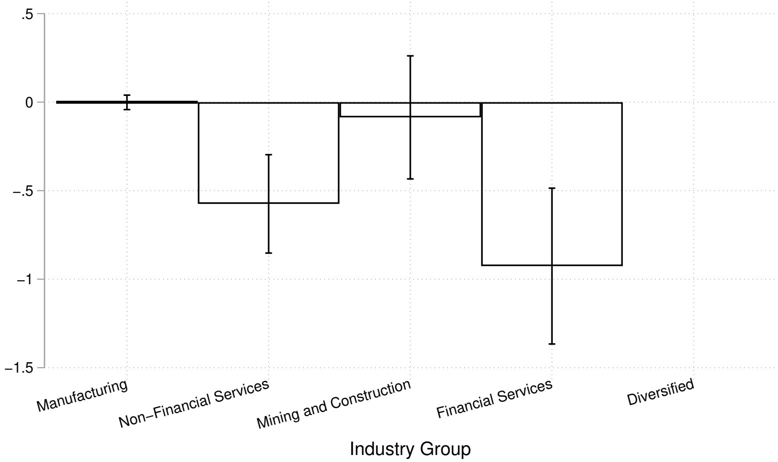
Notes: This figure presents the point estimates and their 95% confidence intervals for the event study estimating Equation (2).

Heterogeneity: by Firm Size



Notes: This figure summarizes the point estimates and their 95% confidence intervals separately for two sub-groups based on firm size deciles: firms in Deciles 1 through 5 and firms in Deciles 6 through 10.

Heterogeneity: by Industry



Notes: This figure shows the point estimates and their 95% confidence intervals by industry group. We define five industry groups based on 6-digit CMIE industry codes: Manufacturing, Non-Financial Services, Mining and Construction, Financial Services.

Heterogeneity: by Region

	(1)	(2)
	Cluster 1	Cluster 2
β	-0.104***	-0.041
	(0.022)	(0.055)
N	24075	4159
R^2	0.66	0.73

Notes: * p<0.10 ** p<0.05 *** p<0.01. Robust standard errors in the parentheses. This table summarizes results for two regional clusters, factoring in India's energy distribution. Cluster 1 includes the Northern, Southern, and Western Zonals, where renewable energy is rapidly expanding and constitutes a relatively larger share of the total energy mix. Cluster 2 consists of North Eastern, Eastern, and Central Zonals, where renewable energy has a smaller presence.

▸ Zonal Divisions

Heterogeneity: by Energy Source

	(1)	(2)	(3)
	Emission from Renewable	Log(Emission from Conventional)	Share from Renewable
β	1.758**	-0.314***	0.510***
	(0.658)	(0.057)	(0.294)
Incidence Rate Ratios	5.80		1.67

Notes: * p<0.10 ** p<0.05 *** p<0.01. Robust standard errors in the parentheses. We differentiate emissions by their sources, categorizing them as either conventional or renewable energy, and consider three additional outcome variables: a) CO2 emissions from renewable energy, b) CO2 emissions from conventional energy (in logarithmic form), and c) the share of emissions from renewable energy, calculated as CO2 Emission from Renewable/Total CO2 Emission.

Model Set-up

1. A Cobb-Douglas production function: $Y = AK^{\psi_K}E^{\psi_E}L^{\psi_L}$, where Y is the total production and A captures the total factor productivity. ψ_K, ψ_E, ψ_L are output elasticities and $0 < \psi_K + \psi_E + \psi_L < 1$
2. $P = \{p, p^K, p^E, p^L\}$, where p is the price of output and p^K, p^E, p^L as the price of capital, energy, and labor, respectively
3. Let t denote the corporation tax, with a tax deduction of c% applied proportionally to it $\Rightarrow$ revenue of production is $(1 - t(1 - c))pY$
4. WLOG, assume a competitive product and input market

Model Set-up

5. Two types of energy: cleaner energy with fewer carbon emissions (E^c) and dirtier energy with more carbon emissions (E^d)
6. p^{E^d} is the unit price of the dirtier energy
7. For cleaner energy, on top of the unit price p^{E^c}, there is a fixed cost f
8. Energy consumption: $E_s = \left[\delta_c (E_s^c)^{\rho_s} + \delta_d (E_s^d)^{\rho_s}\right]^{\frac{1}{\rho_s}}, s \in \{M, N\}$
   - δ_c and δ_d are the distribution parameter, and $\delta_c + \delta_d = 1$
   - ρ_s is the substitution parameter
   - For non-manufacturing firms: $\rho_N = 1$:

$$E_N = \delta_c E_N^c + \delta_d E_N^d$$

▸ Emission by Industry and Fuel Type

Derivations

1. Solving the profit maximization and cost minimization problems, it can be shown that:

$$\frac{\partial E^*}{\partial c} > 0$$

2. Since $E_N = \delta_c E_N^c + \delta_d E_N^d$,

$$E_N^{c*} = \begin{cases} E^*/\delta_c & \text{if } f < E^*(\frac{p^{E^c}\delta_c + p^{E^d}\delta_d}{\delta_d \delta_c}) \text{ and } p^{E^d} > p^{E^c}\lambda \\ 0 & \text{otherwise} \end{cases}$$

$$E_N^{d*} = \begin{cases} E^*/\delta_d & \text{if } f > E^*(\frac{p^{E^c}\delta_c + p^{E^d}\delta_d}{\delta_d \delta_c}) \text{ or } p^{E^d} < p^{E^c}\lambda \\ 0 & \text{otherwise} \end{cases}$$

where $\lambda = \delta_c / \delta_d$

Derivations

3. Because $\frac{\partial E^*}{\partial c} > 0$,

$$\frac{\partial Pr[f < E^*(\frac{p^{E^c}\delta_c + p^{E^d}\delta_d}{\delta_d \delta_c})]}{\partial c} > 0$$

4. For manufacturing firms, the share of cleaner energy consumption can be written as:

$$\frac{E^c}{E_M^*} = \frac{\gamma}{(\delta_c \gamma^{\rho_M} + \delta_d)^{1/\rho_M}}$$

where $\gamma = \left(\frac{(1-\delta_c)p^{E^c}}{\delta_d p^{E^d}}\right)^{\frac{1}{\rho_M - 1}}$

Takeaways

- Larger firms experience greater impact of SEZs: E^* would be greater for larger firms and $Pr[f < E^*(\frac{p^{E^c}\delta_c + p^{E^d}\delta_d}{\delta_d \delta_c})]$ would also be higher for them
- f may vary across regions, hence $\partial Pr[f < E^*(\frac{p^{E^c}\delta_c + p^{E^d}\delta_d}{\delta_d \delta_c})] / \partial c$ varies
- Infinitesimal effects for manufacturing firms: $\partial(E^c / E^*_M)/\partial c = 0$
- Sizable impact for non-manufacturing firms: there are chances that they shift entirely to the cleaner energy in the equilibrium!

Conclusion

- Although SEZs are primarily designed to stimulate economic growth, our findings reveal a significant unintended consequence: a notable 29% reduction in carbon emissions among firms located within SEZs compared to similar firms outside these zones
- Place-based policies can be powerful tools in steering industrial sectors towards greener, more sustainable practices
- SEZs demonstrate the potential to align economic growth with environmental protection
- Heterogeneous impacts underscore the need for tailored approaches and targeted interventions to maximize their environmental benefits

Thank you!

Appendix: Carbon Emission Factors (Example)

Source: EPA's GHG Emission Factors Hub https://www.epa.gov/climateleadership/ghg-emission-factors-hub

Energy Source	kg CO2 per unit of Energy Source	Unit of Energy Source	kg CO2 per MMBtu of Energy Source
Agricultural Byproducts	975	short ton	118.17
Biodiesel (100%)	9.45	gallon	73.84
Biogas (Captured Methane)	0.044	scf	52.07
Bituminous Coal	2325	short ton	93.28
Coal Coke	2819	short ton	113.67
Coke Oven Gas	0.03	scf	46.85
Crude Oil	10.29	gallon	74.54
Distillate Fuel Oil No.1	10.18	gallon	73.25
Fuel Gas	0.08	scf	59
Heavy Gas Oils	11.09	gallon	74.92
Kerosene	10.15	gallon	75.2
Lignite Coal	1389	short ton	97.72
Liquefied Petroleum Gases (LPG)	5.68	gallon	61.71
Lubricants	10.69	gallon	74.27
Motor Gasoline	8.78	gallon	70.22
Naphtha (<401 deg F)	8.5	gallon	68.02
Natural Gas	0.05	scf	53.06
Natural Gasoline	7.36	gallon	66.88
Other Biomass Gases	0.03	scf	52.07
Peat	895	short ton	111.84
Petroleum Coke (Solid)	3072	short ton	102.41
Propane	5.72	gallon	62.87
Rendered Animal Fat	8.88	gallon	71.06
Residual Fuel Oil No.5	10.21	gallon	72.93
Residual Fuel Oil No.6	11.27	gallon	75.1
Solid Byproducts	1096	short ton	105.51
Wood and Wood Residuals	1640	short ton	93.8

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Appendix: Summary Statistics (1/3)

Table: Summary Statistics by Treatment Status

	(1)	(2)	(3)	(4)	(5)	(6)
	Treatment Group		Control Group		Control-Treatment	
	Mean	Std.	Mean	Std.	Diff.	t-stats
Firm Age	3.555	1.248	3.560	1.361	0.005	(0.277)
Size Decile	3.996	2.491	4.207	2.430	0.211***	(6.437)
Entity Type	2.136	0.349	2.189	0.392	0.053***	(11.329)
CMIE 6-digits	1.897	1.935	1.794	1.921	-0.103***	(-4.043)
N	6328		62426		68754	

Notes: $*p < 0.10 **p < 0.05 ***p < 0.01$. This table reports the summary statistics by treatment status and the results of t-test for the difference between the two groups.

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Appendix: Summary Statistics (2/3)

Table: Differences in Firm Attributes by Treatment Status, Matched v.s. Unmatched Sample

	(1)	(2)	(3)	(4)
	Firm Age	Size Decile	Entity Type	CMIE 6-digits
	Unmatched Sample			
SEZs	-0.005	-0.211***	-0.053***	0.1031***
	(0.0166)	(0.0328)	(0.0047)	(0.0255)
N	68753	68730	68754	68754
Pair FEs	*No*	*No*	*No*	*No*
	Matched Sample			
SEZs	-0.006	0.004	0.024	0.105
	(0.0412)	(0.0585)	(0.0301)	(0.1746
N	38817	38817	38817	38817
Pair FEs	*Yes*	*Yes*	*Yes*	*Yes*

Notes: $*p < 0.10 **p < 0.05 *** p < 0.01$. This table reports the results regressing firm attributes on the within SEZs indicator separately for matched and unmatched samples, where for the matched sample, pair FEs are included. Robust standard errors in the parentheses.

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Appendix: Summary Statistics (3/3)

	Freq.	Percent
Firm Age		
Before 1950	8,374	10.46
Between 1951 and 1971	8,714	10.88
Between 1972 and 1985	21,295	26.6
Between 1986 and 1990	13,297	16.61
After 1991	28,389	35.46
Between 1991 and 2000	21,547	26.91
Between 2001 and 2005	4,296	5.37
After 2006	2,547	3.18

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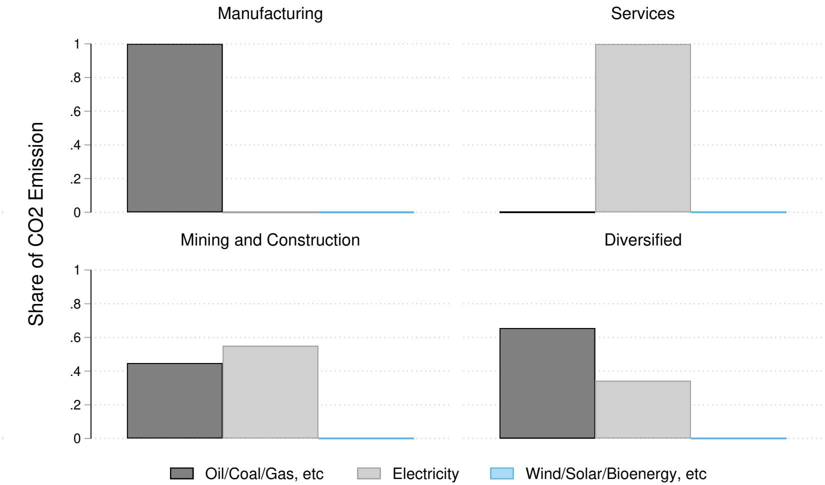
Appendix: Energy Consumption Pattern



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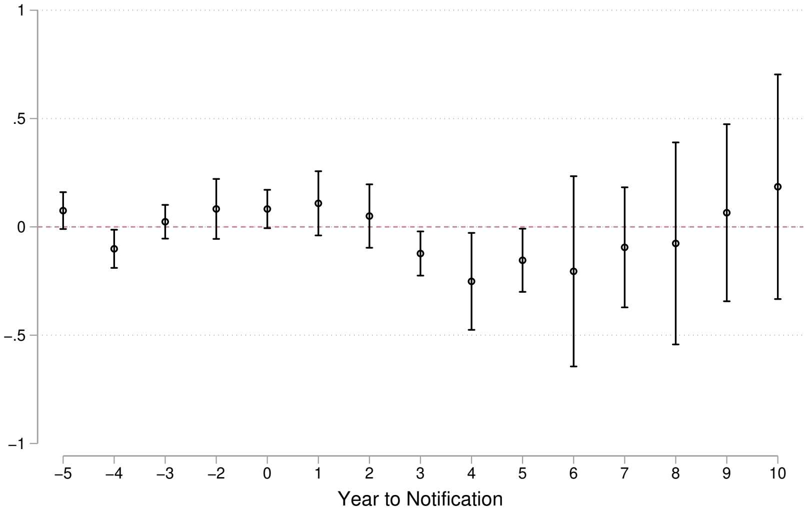
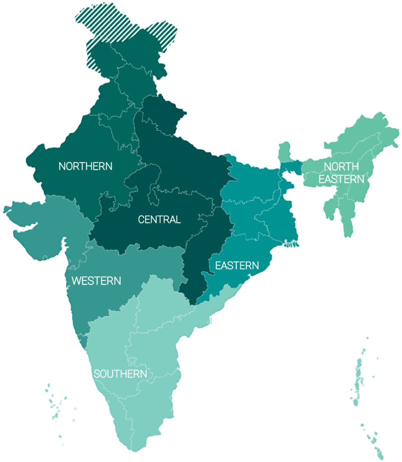
Appendix: csdid Results



Notes: This figure plots the point estimates and 95% Confidence Intervals using the inverse probability weighting (IPW) method. Results are estimated by the csdid command in Stata

Appendix: Zonal Divisions



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